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Evaluation of cyclic fatigue resistance of four heat-treated nickel-titanium single file systems in canals with single curvature - An in-vitro study

Mohammad Daher Altufayli[1], **Basem Salem**[2], **Imad Katbeh**[3], **Pierre Georges**[4]✉, **Roua Kamel Moualla**[5]

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Author Affiliation:
[1]Master student, Faculty of Dentistry, Department of Operative and Endodontic, Tishreen University, Latakia, Syria; ORCID: 0000-0001-9463-8416
[2]Associate professor, Faculty of Dentistry, Department of Operative and Endodontic, Tishreen University, Latakia, Syria; ORCID: 0000-0002-9440-2873
[3]Assistant Professor, Medical Institute, Department of Pediatric Dentistry and Orthodontics, People's Friendship University of Russia, (RUDN) Miklukho-Maklaya Street 10/2, Moscow, Russia; Email: katbeh@bk.ru, ORCID: 0000-0002-4591-7694
[4]Resident student, Medical Institute, Department of Pediatric Dentistry and Orthodontics, People's Friendship University of Russia, (RUDN) Miklukho-Maklaya Street 10/2, Moscow, Russia; Email: pierreig1996@gmail.com, ORCID: 0000-0003-0587-9504
[5]Master Student, Faculty of Dentistry, Department of Operative and Endodontic Tishreen University, Lattakia, Syria; ORCID: 0000-0002-1340-0930

✉**Corresponding author**
Resident student, Medical Institute, Department of Pediatric Dentistry and Orthodontics, People's Friendship University of Russia, (RUDN) Miklukho-Maklaya Street 10/2, Moscow, Russia;
Email: pierreig1996@gmail.com

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ABSTRACT

The anatomy of root canal system has a complex variation, so it is important to have a flexible system that would require minimal preparation of the canal. Nickel-titanium (NiTi) instruments can be separated and broken without previous warning during the root canal preparation, and this separation has been a problem. However endodontic instruments are unable to achieve a complete clean to the root canal system because of many high variability of root canal system complex anatomy , the endodontic instruments which are chosen for root canal preparation play a critical role in accomplishing the main goal for obturation and for the prevention of ledging, zipping ,root canal transportation, file separation, and save the root canal original shape, NiTi instruments properties of memory shape, super elasticity, and resistance to torsional and cyclic fatigue are advantages to their use in preparation of the curved root canal. This study aims to compare the cyclic fatigue resistance of four heat treated nickel–titanium single file systems in Reciprocation movement and rotary movement in curved canals.

Keywords: Cyclic fatigue resistance; reciprocation motion; nickel-titanium rotary system.

1. INTRODUCTION

The use of nickel-titanium (NiTi) alloys for cleaning and shaping root canal system makes it faster, easier, and safer than manual instrumentation because of the high flexibility and strength values of NiTi instruments, NiTi instruments properties of memory shape, super elasticity, and resistance to torsional and cyclic fatigue are advantages that led to their use in preparation of the curved root canal. The unexpected fracture of the files occurs because of two different mechanical factors: torsional stress and cyclic fatigue (Shen et al., 2006; Cheung, 2007). Torsional fracture occurs when the instrument tip binds into the canal while the instrument continues its rotation, and consequently

the torque passes the elastic limit of the metal alloy. Cyclic fatigue fracture occurs when the instrument is rotated in a root canal with a curvature and exposed to continuous compression and tension cycles to the point of maximum limit of flexure. Cyclic fatigue fracture has been affected by many variable factors, including instrument motion, the instruments' metal alloy properties, speed, and torque of the preparation setting, cross-sectional form, core mass, and continuous taper of the instrument to the tip (Lopes et al., 2011; Shen et al., 2006).

Reciprocation motion has been submitted to improve the NiTi instruments resistance of cyclic fatigue by producing less stress values than other continuous rotation motion. Moreover, it has been shown that Reciprocation motion yields longer lifespan of instruments regardless of alloy used in manufacturing (Pedulla et al., 2013). Reciproc R25 (VDW, Munich, Germany) is a single-file Reciprocation instrument manufactured from M-Wire. Reciproc was recently developed to Reciproc Blue by modifying it with heat treatment that metamorphoses the molecular mechanical structure of the alloy which led to the introduction of the Reciproc Blue system with s-shape cross section design. This single file system has three main tip sizes (R25-R40-R50) with taper of 08 starting after three millimeters from the end (Reciproc Blue Brochure (2018) VDW Munich).

Recent studies have reported that the blue thermo-mechanical treatment of the alloy increase the flexibility, elasticity and cyclic fatigue resistance of the instruments that use the Reciprocation motion (De-Deus et al., 2017; Keskin et al., 2017). One Curve (Micro-Mega, Besancon, France) is a single file system that uses continuous rotation motion for shaping and cleaning the whole length of the root canal with one instrument. It is manufactured from heat-treated NiTi alloy. This new alloy has a file shape memory advantage, Pre-bendable, variable cross-section combined with continuous rotation, this ensures excellent cutting efficiency. This single file system has a single design with a 06 taper and 25 tip size, Moreover, the manufacturer of the file states that C-Wire technology reduces the instrument from sticking, threading, and binding to the canal walls with the ability to easily access to the root canal (Fanta Dental Endodontic Catalog).

F-one (Fanta, Changzhou, china) with an AF-TM blue wire, which is a special heat-treated wire developed from NiTi alloy with flexibility and high resistance to cyclic fatigue. F-one is a single file system with an s-shape cross section; non-cutting tip flat design provides better cutting performance and debris removal using a continuous rotation motion to shape the root canal (Fanta Dental Endodontic Catalog). R3- Reciproc (Fanta, Changzhou, china) with an AF-TM blue wire which is a special heat-treated wire developed from NiTi alloy with flexibility and high resistance to cyclic fatigue. R3- Reciproc is a single file system with a design that provides better cutting efficiency and safety (Abdul- Ameer et al., 2020). Experimental testing of the fatigue resistance of nickel titanium instruments uses standardized artificial metal canals that having radius of curvature of 5 mm, and angles of curvature ranging from 30 to 90° (Larsen et al., 2009).

Studies reported that fatigue resistance of nickel titanium instruments was increased when the angle of curvature was decreased and vice versa, and the cyclic fatigue resistance was increased when the radius was increased too. Most of the experimental design of the artificial canals has focused on a curvature at the middle and apical section of the root canals (Larsen et al., 2009; de Vasconcelos et al., 2016; Dosanjh et al., 2017).

This study aimed at evaluating the cyclic fatigue resistance (CFR) of four different NiTi Reciprocation and rotary instruments in artificial canals: Reciproc Blue –One curve –F one –R3 Reciproc. The tested null hypothesis showed measurable difference of cyclic fatigue resistance between the four tested systems.

2. MATERIALS AND METHODS

The study was registered by Tishreen University Council, Syria (protocol code 559, date 11/2019). Four NiTi single file systems Reciproc R25 (VDW, Munich, Germany) One Curve (Micro-Mega, Besancon, France) F-one (Fanta, Changzhou, china) R3- Reciproc (Fanta, Changzhou, china) were tested using the artificial metal canal that was designed and manufacture by authors (Fig.1).

The devices were made from stainless steel and were designed with parts that can carry the endo motors; the artificial metal canals had different angles of curvature 45-60-90 degrees, and a diameter of 1.5 mm. In this study we tested the endodontic instruments in an artificial canal with an overall length of 19 mm, a single curvature of 60 degrees at the last 5 mm of the canal and a radius of 5mm. A total of 48 files of all systems were tested, all files had a length of 25mm and the same tip size of 0.25 mm with different tapers, the 0.8 taper for Reciproc Blue decreases toward the end of file starting at 3mm from the tip and 0.6 taper for the other single file systems (one curve – F-one – R3 Reciproc). To test their cyclic fatigue resistance in a single curvature artificial metal canal, atotal of four groups were tested as follows:

Group one: 12 files Reciproc Blue 25/08 in acanal with single curvature.

Group two: 12 files one curve 25/06 in a canal with single curvature.

Group three: 12 files R3 Reciproc 25/06 in a canal with single curvature

Group four: 12 files F-one 25/06 in a canal with single curvature.

Figure 1 Artificial metal canal that was designed and manufactured by the authors from (stainless steel) with angles of curvature 45-60-90 degrees respectively.

Each instrument was tested according to the manufacturer settings. The programmed settings for each test group was saved in the hand piece memory of each system. All instruments were activated using a (l: l) E-connect pro hand piece (Eighteenth - china). The Reciproc blue was used by the manufacturer settings: speed 300 rpm, and an angle of 150 clockwise direction, and 30 counter clockwise direction. The R3 Reciproc was used by the manufacturer setting: speed 300 rpm, and angle of 150 clockwise direction, and 30 counter clockwise direction.
Onecurve was tested: speed 300 rpm, and a torque of 2.5 ncm.
F-one group was tested: speed 450 rpm, and a torque of 2.5 ncm.

To reduce the effects of friction and to minimize the temperature effects we used glycerin oil inside the artificial root canal at every test (Kiefner et al., 2014; Hülsmann et al., 2019). Every instrument was tested until it fractured. The time to fracture (in seconds) (TF) was calculated by a timer application on Digital Three-Channel Alarm Timer (Fisherband™ Traceable™) we counted to two fractions of a second. The number of cycles to fracture was calculated by this equation.

NCF = Rpm (speed) x time to fracture/60 second (Kırıcı et al., 2019). The length of the fractured part of the tested files was measured using an endodontic ruler.

Statistical analysis

Kruskal-Wallis with bonferroni post hoc test was used for to assess differences between time to fracture (TF) and Number of cycles to fracture (NCF). The statistical program SPSS version 20.0 (Chicago, IL, USA) was used for data analysis. The results were considered significant if $p \leq 0.05$.

3. RESULTS

The data for the values of the time to fracture (TF); that represent the cyclic fatigue resistance for each instrument was present at Table 1. The time until fracture of the single file systems ranged from 2.56 to 44.25 minutes in different tested groups. The Reciproc Blue group had significantly higher TF compared to the other test groups, followed by the R3 Reciproc, one curve and F-one. The Bonferroni post hoc test was used to determine the difference between the experimental groups. The Reciproc Blue group had significantly better TF than one curve and F-one groups ($P<0.05$). No significant difference was measured between Reciproc Blue group and R3 Reciproc ($P>0.05$). The one curve group had no significant difference with both the R3 Reciproc group and the F-one group ($P>0.05$). The R3 Reciproc group had significantly better TF than F-one group ($P<0.05$). The data for the mean values of the number of cycles to fracture (NCF) are presented in table 1.

Table 1 The values of time to fracture, number of cycles to fracture, and length of broken part, that represents the fatigue resistance for each experimental group.

Groups	Mean TF	Standard deviation	Mean NCF	Standard deviation	Mean LBP	Standard deviation
Group One Reciproc Blue	34.65	8.02	173.26	40.11	6.96	0.62
Group Two one curve	11.49	3.04	57.46	15.20	5.61	0.42
Group Three R3 Reciproc	26.26	9.31	131.29	46.54	6.36	0.45
Group Four F- one	3.88	1.38	29.11	10.36	6.86	0.48

The Reciproc Blue group had significantly higher NFC followed by the R3 Reciproc, one curve, and F-one. The Bonferroni post hoc was test to determine the difference between the experimental groups. The Reciproc Blue group had significantly better NCF than one curve and F-one groups ($P<0.05$). The R3 Reciproc group had significantly better NCF than F-one group and one curve group ($P<0.05$). No significant difference was measured between Reciproc Blue group and R3 Reciproc ($P>0.05$). No significant difference was measured between one curve group and F- one group ($P>0.05$).

Broken part length (LBP)

No significant difference was measured between the experimental groups except the difference between the F- one group and both of Reciproc Blue and R3 Reciproc groups ($P=0.000$).

4. DISCUSSION

The data regarding the cyclic fatigue behavior of NiTi instruments using Reciprocation motion or continuous rotation motion were limited. The presented study aimed to compare fatigue resistance of F-one rotary, Reciproc blue, one curve and R3 Reciproc instruments using artificial canal designs from stainless-steel at 60-degree curvature. Previous studies reported that the Reciprocation motion enhanced CFR of the nickel titanium preparation systems- Several processes have been used to test in vitro nickel titanium cyclic fatigue resistance in endodontic preparation systems (Yared, 2008; Plotino et al., 2015; De-Deus et al., 2010).

The best way to assess the CFR of the endodontic instruments is to use natural human teeth; but we have several problems to this method, because of the complexity of root canal system anatomy such as: curvature angle, dentin thickness, the root canal length, and the root canal calcification that may not appear in radiographic images (Ajuz et al., 2013). Therefore, the use of simulated artificial root canal in a stainless-steel metal block to test the cyclic fatigue resistance may be considered acceptable (De-Deus et al., 2010; Varela-Patino et al., 2010; Gavini et al., 2012). We used the Larson design in this study to test the cyclic fatigue of the single file systems (Larsen et al., 2009) the diameter of the artificial root canal in this study was 1.5mm to decrease the effects of contact with the metal walls of the canal to minimize the effects of temperature (Kiefner et al., 2014).

The cyclic fatigue of the endodontic instruments was affected by several elements such as the rotation speed and root canal curvature (Yared et al., 2001), torque and the human error of the operator (Varela-Patiño et al., 2010), the differences of the cross-section design (Pedulla et al., 2013), and the influence of the alloy tube that the rotary instrument was made from (Alcalde et al., 2017). Figueiredo et al., (2009) showed no influence of the M-wire at improving the cyclic fatigue resistance, in contrast with Keskin et al., (2017) which showed that Reciproc blue M-wire had higher cyclic fatigue resistance, which coincides with our study. It is crucial to note that the current results can be affected by three main differences between the experimental systems that we tested in this study: The differences of the cross section; The difference between the blue M-wire, C-wire, AF, Blue wire; The large taper of the Reciproc blue (0.08) compared with the other systems (0:06).

This study compared the cyclic fatigue resistance between four different single file systems that used different rotation motions with several cross sections and NiTi alloy. The cyclic fatigue resistance of the Reciproc blue R25 instruments was compellingly higher than the other systems. Reciproc Blue is made from an alloy that is covered with an oxide layer due to the thermo-mechanical treatment (De-Deus et al., 2017), and it has a S-shaped cross section with higher taper (0.08)-More than- any of the rotary systems used in this study (Topçuoğlu et al., 2017). The R3 Reciproc showed higher resistance to cyclic fatigue than the one curve

and F-one systems when used in this study. The single file systems that used the Reciprocation motion showed higher cyclic fatigue resistance than the rotary instruments that used the continuous rotation motion. The Reciprocation motion has shown to be an effective motion to prepare a curved root canal while reducing cyclic fatigue (De-Deus et al., 2010; Varela-Patino et al., 2010; Gavini et al., 2012). First the one curve showed higher cyclic fatigue resistance than the F-one.

In another study the C-wire of one curve showed higher cyclic fatigue resistance than the M-wire endodontic preparation system that used the same motion (Topçuoğlu et al., 2020). No significant difference was measured between the one curve and R3 Reciproc in terms of cyclic fatigue resistance. It was found that controlled memory rotary files as the one curve C-wire showed great resistance to cyclic fatigue preparing curved root canals (Topçuoğlu et al., 2020).

The present study showed significant difference in length of fractured fragments of the experimental instruments, the one curve systems showed the shortest length of fractured fragments, probably because of the differences of the cross section along the file length. Fracture of the instruments occurred at the center or below the curvature which affirms the importance of the positioning of the files in the artificial root canal.

5. CONCLUSION

Under the circumstances of this study, the Reciproc blue R25 -0.08 single file system displayed a statistically significantly superior cyclic fatigue resistance and higher fracture resistance when compared to other files tested (F-one, one curve and R3 Reciproc) in simulated artificial root canal made from stainless steel metal with single curvature.

Author Contributions

Mohammad Daher Altufayli: conceptualization, methodology, investigation, data curation; Basem Salem: conceptualization, methodology, investigation, supervision; Imad Katbeh: writing - original draft, writing – review & editing; Pierre Georges: writing - original draft, writing – review & editing; Roua Kamel Moualla: writing-review & editing.

Conflicts of interest

The authors declare that they have no conflict of interest.

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Data and materials availability

All data associated with this study are present in the paper.

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